"On the Construction of some Mercury Standards of Resistance, with a Determination of the Temperature Coefficient of Resistance of Mercury." By F. E. SMITH, A.R.C.Sc., Assistant at the National Physical Laboratory. Communicated by R. T. GLAZEBROOK, F.R.S. Received March 10,—Read March 17, 1904.

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(Abstract.)

This paper contains an account of the construction and measurement of eleven mercury standards of resistance at the National Physical Laboratory, Teddington.

It is divided into three parts: (*a*) theory of construction; (*b*) determination of the mechanical constants: (*c*) measurement of resistance, and deductions.

(*a*) *Theory of Construction.*

The definition of the international ohm necessitates the determination of a length and a mass only, the resistance of a uniform column of mercury of length, L. cm., and of mass, W. gr., being

$$\frac{L^2}{W} \cdot \frac{14{\cdot}4521}{106{\cdot}3^2} \text{ international ohms.}$$

The difficulties of accurately evaluating L^2/W are discussed in the paper. The method finally adopted for the determination of this ratio differs from those which have been previously employed. A quantity proportional to L^2/W was first of all determined for different, but practically similar portions of a selected tube. The tube was then broken into three parts, the positions of fracture being carefully chosen, so that a mercury column occupying the central portion should have a nominal resistance of 1 ohm. The ratio L^2/W for this central portion was calculable from the previous observations. It is shown that this method admits of measurements of a high degree of accuracy, while all the operations involved are of a simple nature.

The effect of liquid and gaseous films in contact with the glass is briefly discussed. If the same cycle of operations is always adhered to, it is shown that such films produce no disturbing effects.

The fact that the axis of a tube may be undulatory in character, is proved to be a very serious obstacle to an accurate computation of the resistance of a mercury column. Thus, it is quite possible for the radius of curvature at any part of the axis to be as small as 40 cm., and for the maximum displacement of the curve from a straight axis to be 0·015 mm. only, and yet, under such circumstances, the computed resistance is 0·0036 per cent. greater than that calculated by the usual

formula. If such an axis were projected and examined, the curve could not be distinguished by the eye from a straight line.

The correction for conical form was obtained by a method very similar to those previously employed by other observers.

(*b*) *Determination of the Mechanical Constants.*

The lengths of the mercury columns, and of the tubes, were measured in a water bath comparator by Mr. B. F. E. Keeling, the temperature of the mercury and of the glass being accurately known to 0°·02 C. The mass of the mercury was determined with a probable error of about 0·0005 per cent. These determinations enabled the mean cross-sections of different parts of the tube to be evaluated. From the results, the mean cross-section of the standard portion was deduced, and, finally, that length of a uniform mercury column of similar cross-section that would have a resistance of 1 international ohm. The consistency of the results obtained from different fillings of the tubes, each thread of mercury occupying a slightly different position, may best be judged from the results of actual observations. The following values are for the first three standards constructed. The horizontal lines in the table represent separate fillings of the three tubes:—

Standard.	M.	P.	T.
Length of the mercury column possessing a uniform cross-section equal to the mean of that of the standard, and having a resistance of one international ohm.	59·0336 cm.	63·5493 cm.	57·7801 cm.
	59·0326 ,,	63·5485 ,,	57·7808 ,,
	59·0328 ,,	63·5494 ,,	57·7805 ,,
	59·0337 ,,	63·5484 ,,	

The results with the remaining eight tubes are equally good.

(*c*) *Measurement of Resistance, and Deductions.*

The standards were erected in three fashions. In the first of these, two other glass tubes were connected to the ends of each standard by means of a special connector. The ends of the tubes thus brought into contact were of the same cross-section, and the shapes of the sections were also identical. An adjustment was provided for, which insured the absence of internal irregularities at the junctions. Thin pieces of platinum foil, interposed at the points of union, acted as potential leads, and enabled the resistance to be measured. The value thus obtained was for a column of mercury completely filling the tube, and terminated by planes at the ends of the tube. This mode of erection answers capitally with care, but many precautions have to be taken.

The second and third modes of fitting up the standards introduced

"end corrections" to the resistance. The ends of the tubes passed into comparatively large vessels containing mercury, into which two leads were introduced.

For the measurement of resistance, three methods were employed; the Kelvin double bridge, the potentiometer, and the Carey Foster bridge. The last of these methods is shown to be subject to a considerable error when mercury standards are measured.

The following table contains the results of the resistance measure-

Standard.	Res. in ohms (Kelvin double bridge).	Res. in ohms (potentiometer).	Mean value of res.	Difference from mean parts in 100,000.	
M	1·001162	1·001167	1·001164	-0_2	$+0_3$
	1·001164	1·001162		$\pm 0_0$	-0_2
	1·001166	1·001165		$+0_2$	$+0_1$
P	1·000467	1·000468	1·000470	-0_3	-0_2
	1·000468	1·000472		-0_2	$+0_2$
	1·000472	1·000471		$+0_2$	$+0_1$
T	1·000277	1·000273	1·000278	-0_1	-0_5
	1·000281	1·000280		$+0_3$	$+0_2$
	1·000276	1·000281		-0_2	$+0_3$
U	1·000215	1·000213	1·000217	-0_2	-0_2
	1·000216	1·000216		-0_1	-0_1
	1·000222	1·000218		$+0_5$	$+0_1$
V	1·001462	1·001455	1·001462	$\pm 0_0$	-0_7
	1·001468	1·001462		$+0_6$	$\pm 0_0$
	1·001463	1·001465		$+0_1$	$+0_3$
W	1·000156	1·000161	1·000153	$+0_3$	$+0_8$
	1·000152	1·000151		-0_1	-0_2
	1·000146	1·000151		-0_7	-0_2
X	1·001147	1·001147	1·001151	-0_4	-0_4
	1·001154	1·001151		$+0_3$	$\pm 0_0$
	1·001155	1·001152		$+0_4$	$+0_1$
Y	1·000356	1·000354	1·000350	$+0_6$	$+0_4$
	1·000347	1·000350		-0_3	$\pm 0_0$
	1·000348	1·000346		-0_2	-0_4
Z	1·001387	1·001391	1·001389	-0_2	$+0_2$
	1·001389	1·001384		$\pm 0_0$	-0_5
	1·001392	1·001393		$+0_3$	$+0_4$
G	1·001130	1·001135	1·001135	-0_5	$\pm 0_0$
	1·001138	1·001135		$+0_3$	$\pm 0_0$
	1·001131	1·001132		-0_4	-0_3
S	1·001053	1·001054	1·001057	-0_4	-0_3
	1·001055	1·001061		-0_2	$+0_4$
	1·001061	1·001057		$+0_4$	$\pm 0_0$

ments when the mode of erection introduced the "end correction," but the fittings were not adapted for the measurement of resistance on the Carey Foster bridge.

Each horizontal line indicates a separate filling.

The unit of resistance employed in the evaluation of the standards is that derived from the coils belonging to the British Association, and assumed as equal to 10^9 C.G.S. units.

The difference between the observed resistance, employing this unit, and the calculated resistance in international ohms, is shown in the following table :—

Standard.	Mode of Erection I.			
	Observed resistance in ohms.	Theoretical resistance in international ohms.	Observed — theoretical value.	Difference from mean.
M	$1 \cdot 00005_2$	$0 \cdot 99994_6$	$0 \cdot 00010_6$	$+0 \cdot 00002_1$
P	$0 \cdot 99938_4$	$0 \cdot 99930_4$	$0 \cdot 00008_0$	$-\ 0_5$
T	$0 \cdot 99912_1$	$0 \cdot 99904_6$	$0 \cdot 00007_5$	$-\ 1_0$
U	$0 \cdot 99912_9$	$0 \cdot 99904_6$	$0 \cdot 00008_3$	$-\ 0_2$
V	$1 \cdot 00043_3$	$1 \cdot 00036_1$	$0 \cdot 00007_2$	$-\ 1_3$
W	$0 \cdot 99915_2$	$0 \cdot 99905_5$	$0 \cdot 00009_7$	$+\ 1_2$
X	$1 \cdot 00006_3$	$0 \cdot 99998_0$	$0 \cdot 00008_3$	$-\ 0_2$
Y	$0 \cdot 99926_3$	$0 \cdot 99915_5$	$0 \cdot 00010_8$	$+\ 2_3$
Z	$1 \cdot 00032_5$	$1 \cdot 00024_8$	$0 \cdot 00007_7$	$-\ 0_8$
G	$1 \cdot 00034_2$	$1 \cdot 00027$	$0 \cdot 00007$	$-\ 1$
S	$1 \cdot 00025_4$	$1 \cdot 00016$	$0 \cdot 00009$	$+\ 1$
		Mean	$0 \cdot 00008_5$	

Another series of observations shows that the resistance of the unit employed as 1 international ohm at the Reichsanstalt is greater than the resistance of the international unit derived from the eleven mercury standards constructed at the National Physical Laboratory by

$$0 \cdot 00002_0 \text{ ohm.}$$

A comparison with the results obtained by Dr. Glazebrook in 1888 for the specific resistance of mercury indicates that the unit of resistance, as used at the Cavendish Laboratory, Cambridge, in 1888, may still be recovered.

From this it follows that—

$$\left.\begin{array}{l}\text{Resistance of 1 international}\\ \quad\text{ohm (as derived at the}\\ \quad\text{N.P.L.)}\end{array}\right\} - \left\{\begin{array}{l}\text{Res. of unit employed and}\\ \quad\text{assumed as equal to } 10^9\\ \quad\text{C.G.S. units}\end{array}\right\}$$

$$= 0 \cdot 00008_5 \text{ ohm.}$$

The temperature coefficients of resistance of—

(1) Mercury in Jena 16‴ glass,
(2) Mercury in verre dur glass,
(3) A constant volume of mercury,

have also been determined for a range of temperature 0° C. to 22° C. The results are as follows :—

(1) Mercury in 16‴ glass—

$$R_T = R_0 [1 + 0{\cdot}00088018T + 0{\cdot}00000105793T^2].$$

(2) Mercury in verre dur glass—

$$R_T = R_0 [1 + 0{\cdot}00088036T + 0{\cdot}00000103094T^2].$$

(3) A constant volume of mercury—

Deduced from (1),

$$R_T = R_0 [1 + 0{\cdot}00088788T + 0{\cdot}0000010564T^2]$$

Deduced from (2),

$$R_T = R_0 [1 + 0{\cdot}00088776T + 0{\cdot}0000010376T^2],$$

T being the temperature on the hydrogen scale.

The whole of the observations have been carried out at the National Physical Laboratory. To the director, the author has to express his great indebtedness in all departments of the work. To his colleague, Mr. B. F. E. Keeling, the success of the linear measurements is entirely due.